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Saxon J. Ryan

Iowa State University, saxon@iastate.edu

Gretchen A. Mosher

Iowa State University, gamosher@iastate.edu

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Safety

Use of Risk Mapping Tools to Identify Hazards in Bulk Material Handling

Mr. Saxon J. Ryan, Iowa State University, 3332 Elings Hall, Ames, Iowa 50011, 515-294-0228, saxon@iastate.edu

Dr. Gretchen A. Mosher, Iowa State University, 3331 Elings Hall, Ames, Iowa 50011, 515-294-6416
gamosher@iastate.edu

Introduction

The identification, assessment, and mitigation of risk in complex systems are challenging tasks. Risk analysis is often used in complex systems to reduce the probability of negative events occurring in such systems, and to enhance the decisions made under uncertain conditions (Clemons & Simmons, 1998). The conventional risk analysis framework includes three sub-components: assessment of risk, management of risk, and communication of risk (Codex, 2007). Mapping the risk analysis process within a specific system allows for the identification of the most high-stakes hazards, allowing an efficient application of management and mitigation activities (Clemons & Simmons, 1998; Stamatelatos et al., 2002).

One example of a complex system is one which processes bulk materials such as grain. The bulk materials handling system is becoming more complex than previously, with evolving production practices, changing customer demands, and increased legislative requirements (Thakur, Wang, & Hurburgh, 2010). Little emphasis has been given in current and previous research on use of risk analysis in these systems (Kingman & Field, 2005). Therefore, the focus of this paper is to provide an overview of risk tools that can be used in the bulk materials environment, to discuss the ability of the risk tools to measure hazards quantitatively, and to recommend appropriate usage within the bulk materials handling industry. Implications for managers on the interpretation of information generated by risk analysis tools will conclude the paper.

Risk Analysis Framework

Most risk analysis tools are based on the assumption that risk is calculated by considering both the probability of exposure or occurrence to the hazard and the consequence or severity of the hazard. Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) are two risk mapping tools that may be used to identify and assess the risks in a system. Both require the analyst to identify the events involved that may lead to a specific undesirable outcome or condition (Clemons & Simmons, 1998; Rausand & Hoyland, 2004). Fault tree analysis and event tree analysis use probability data derived from experimental means or as determined by expert panels (Stamatelatos et al., 2002; Vesely, Goldberg, Roberts, & Haasl, 1981). Probability data are used to quantitatively estimate the likelihood that events will occur and if they do occur, what the consequence of the event will be. Events with a high



probability of exposure, but a low severity are judged to be a low risk, while events with a high probability of exposure and a high severity are considered to be high-risk situations.

Once hazards are identified and assessed, risk assessment matrices can be used to provide guidance on the management of risk within a system (U.S. Department of Defense [U.S. DoD], 2012). Risk assessment matrices provide a repeatable method of identifying the impact of a given risk by providing a scale to judge the occurrence and consequence of an event. Experts normally determine categories within the matrix. A risk management team with extensive knowledge in the related field is often tapped to construct a risk assessment matrix (Clemons & Simmons, 1998; ioMosaic Corporation, 2009).

Using FTA and ETA provides an analyst or manager with the associated probability of occurrence for a given event. When the probability of an event is known, risk can be calculated by crossing the probability of occurrence with the consequences or benefits of that event. The calculation of risk by crossing the probability of occurrence with the consequence or benefit is a quantitative value that can be used for comparison of alternatives, such as a specific set of countermeasures to reduce the risk involved. For managerial decisions, the risk assessment matrix can be used to determine the acceptability of risks and whether action should be taken to reduce the risk of a given event.

Event Tree Analysis

Event tree analysis (ETA) is a technique used to visually identify and evaluate the causal pathway that follows an initiating event (Ericson, 2005). ETA is based on binary logic, where the event occurs or does not. Because there is no partial failure or success, ETA provides a valuable assessment of the probability of occurrence for negative events (The Institution of Engineering Technology, 2010). ETA evaluates all possible paths following an initiating event that leads to an outcome and its corresponding probability of occurrence (Ericson, 2005), with each "branch" illustrating the probability for one specific event pathway. The ETA output, which reflects the probability of occurrence, is then paired with information on the consequence of the occurrence to calculate risk involved in the system being investigated. Although ETA represents a very powerful and useful calculation, populating the "branches" with accurate probabilities can be a major challenge for analysts in that other analysis tools may need to be used to do so (Ericson, 2005; Rausand & Hoyland, 2004).

An example of an event tree in Figure 1 starts with the initiating event at the leftmost part of the event tree where branches stem from it in a success versus failure logic. Following the top tier successes to the success outcome A, there is a calculation required to quantify the probability of the outcome. Under success outcome A Equation 1 can be used to provide the probability for the success outcome A. To arrive at success outcome A the system is mapped so that events one through 4 must occur successfully to reach outcome A.

$$P(A) = (P(IE)) (P(1s)) (P(2s)) (P(3s)) (P(4s)), \quad (1)$$



where

$P(A)$ =The probability of event A; $P(IE)$ =The probability of the initiating event; $P(Xs)$ =The probability of success event X.

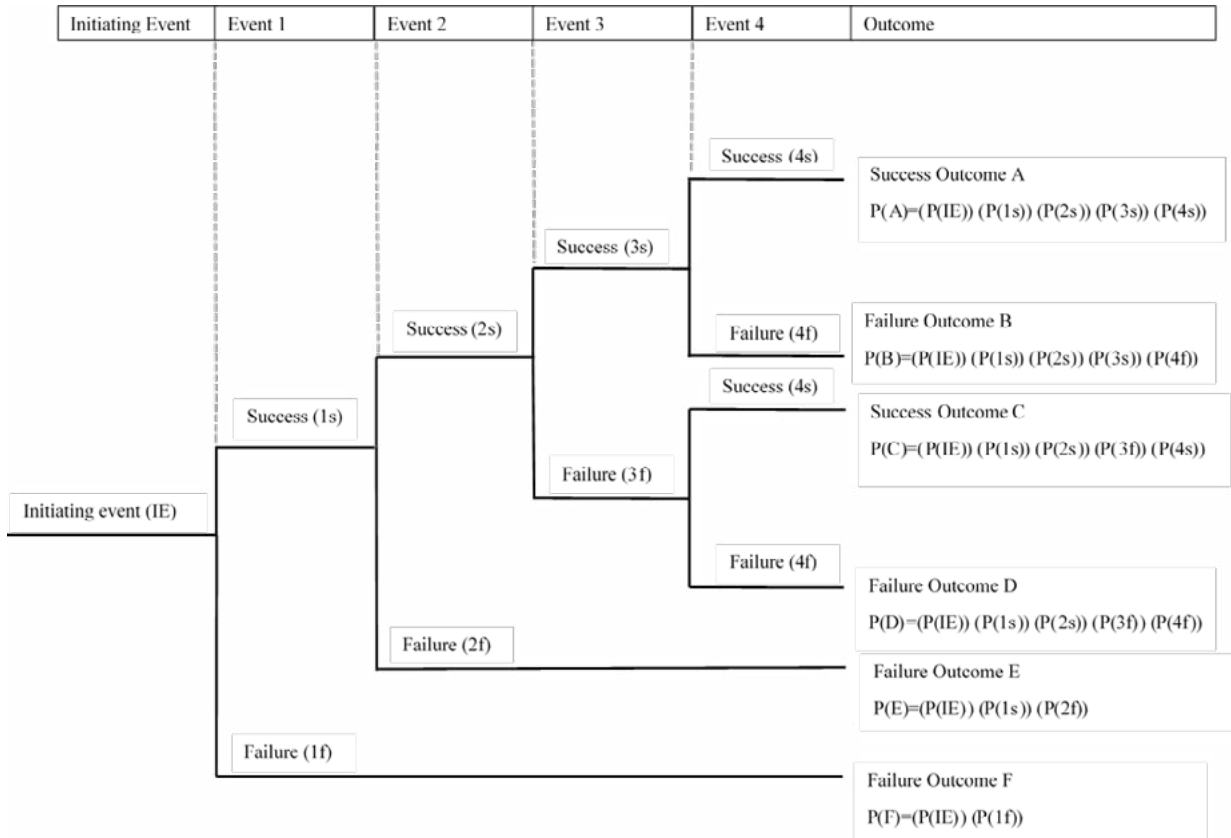


Figure 1 Example Event Tree

Observation of the failure outcome B shows that the path has changed only at event 4, which ultimately leads to a failed outcome. The calculation of failure outcome B follows the same procedure as for success outcome A except that the last quantity in the equation, $P(4s)$, must now be changed to $P(4f)$ to reflect the failure of event 4. This minor change in the process results in a system failure. To calculate the probability of failure in this case, the $P(B)$ is calculated in Equation 2.

$$P(B)=(P(IE)) (P(1s)) (P(2s)) (P(3s)) (P(4f)), \quad (2)$$

where

$P(B)$ = The probability of event B; $P(IE)$ = The probability of the initiating event; $P(Xs)$ =The probability of success event X; $P(Xf)$ =The probability of failure event X.



Single point failures are critical to identify because there are no mitigating or intervening events to prevent the failure. A situation without any intermediate events to prevent the failure of the system if a single event occurs can be seen in the equation for outcome F. Equation 3 shows that there are fewer terms, resulting in a larger probability, given that in the multiplication of probabilities using decimals, the more terms in the equation the smaller the probability will be (Rausand & Hoyland, 2004).

$$P(F)=(P(IE))(P(1f)), \quad (3)$$

where

$P(F)$ =The probability of event F; $P(IE)$ = The probability of the initiating event; $P(Xf)$ =The probability of failure event X.

Finally, to calculate the overall probability of failure and success for the system, failure outcomes and success outcomes are added together from their respective domains. Because event trees are binary, the outcomes are an “or” statement, meaning that no two or more outcomes can occur at the same time.

Event tree analysis has the potential to address existing difficulties of measuring the risk in the bulk materials supply chain. One advantage of ETA is that it will output both successes and failures generated from the initiating event, allowing the analyst to simultaneously operate in and compare both the success and failure domain (Clemons & Simmons, 1998; Ericson, 2005; Rausand & Hoyland, 2004).

In the bulk materials system, there is a demand for both a high quality and sustainable product (Thakur, Wang, & Hurburgh, 2009). In order to provide information on supply chain risks requested by selected customers, ETA can identify the successes and failures related to the quality and sustainability aspects in bulk materials handling. ETA can also identify where in the process the failures and successes are most likely to occur. When applied to the complex task of tracing and tracking bulk products, (Thakur et al., 2009), ETA allows complex systems to be modeled in a relatively straightforward manner. This allows analysts to examine each causal pathway for mitigation points (Ericson, 2005; Clemons & Simmons, 1998).

Finally, ETA allows for the insertion of potential mitigation strategies into the model to determine the effectiveness of the countermeasures on the risk before any investment is made in the mitigation method (Clemons & Simmons, 1998). This helps to balance the cost of managing quality and safety in a system with a very low profit margin.

As with most tools, there are limitations to ETA that may present difficulties when used with bulk materials handling. One limitation of ETA is that the initiating event and the causal pathway that follows must be known by



the analyst, which requires analysts to have training and experience in the context being studied (Ericson, 2005; Clemons & Simmons, 1998). Because of the complexity of the bulk materials system, (Golan et al., 2004; Thakur et al., 2009) it may be difficult to find analysts who both understand the system and are involved enough with its causal pathways to make valid probability estimates.

A lack of understating or experience with the system may result in difficulty identifying initiating events that would ultimately lead to an under-analyzed and incomplete assessment of the system. To address a system that has multiple initiating events, an event tree must be constructed for each event (Clemons & Simmons, 1998), a time-consuming process. Finally, ETA can only describe a failure or success; there are no partial successes or failures. For this reason, it is possible to overlook subtle dependencies within the system while modeling (Ericson, 2005). Expert knowledge of the system can limit the influence of these limitations on the final ETA, but it is a key consideration when using the process.

Fault Tree Analysis

Fault Tree Analysis (FTA) works in reverse of ETA, starting the logic system at a specific failure and working backward to find the contributing factors. FTA graphically displays a systematic description of how components of a system could align and lead to an undesirable outcome, termed “the top event” (The Institution of Engineering Technology, 2012). Fault trees are constructed from the failure (the top event) towards each basic causal event until the desired level of detail is reached or until the system events cannot be broken down any further (Lindhe, Rosen, Norberg, & Bergstedt, 2009).

Like the ETA, FTA is a binary system, but, unlike the success and failure branches used by ETAs, fault trees use logic gates. Examples of logic statements used in FTA are shown in Figure 2. Data used to populate an FTA may be qualitative, quantitative, or both, depending on the analyst’s goal (Rausand & Hoyland, 2004). The output from a FTA can provide information to analysts that facilitate managerial decision-making regarding the priority of mitigation tasks (Stamatelatos et al., 2002).

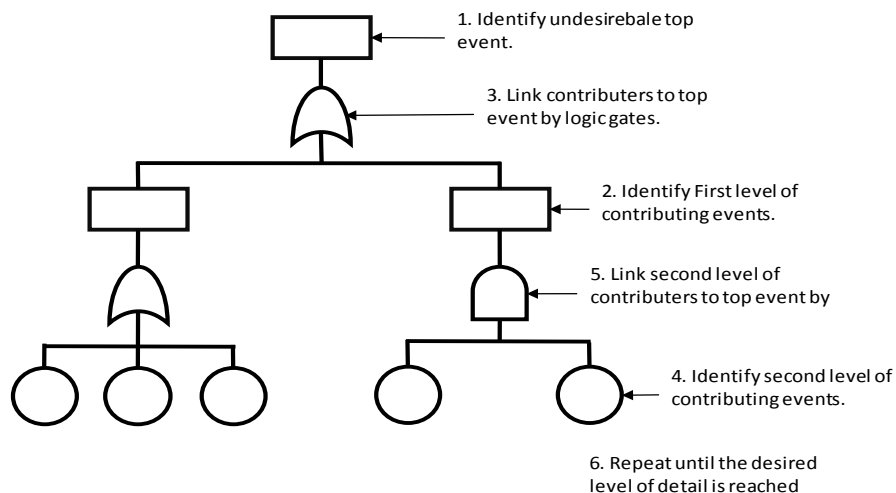



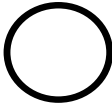


Figure 2. Example of a Fault Tree Analysis

Because fault trees are constructed with logic gates, specific symbols are used to identify different components of the tree. These are shown in Table 1 (Clemons & Simmons, 1998; Rausand & Hoyland). Figure 2 displays an example of a fault tree where the top event is the first item listed, followed by a logic gate (which can be an “and” or an “or” gate) and then proceeds to the first tier events. First tier events are events that happen just before the top event, likewise with second tier events that occur just before the first tier events and so on.

This path of logic gates and events will continue to repeat, branching out, until the desired level of detail or basic events, as defined in Table 1, have been reached. Just as with event trees, fault trees can also identify single point failures. A single point failure in fault tree will display a basic event connected directly to the top event with an “or” gate. Calculations in FTA are similar to those of ETA, but use additional algebra to compute probabilities as described by multiple authors (Clemons & Simmons, 1998; The Institution of Engineering Technology, 2012).



Table 1. Basic FTA Symbols

Symbol	Name	Description
	Event (Top or Intermediate)	<u>Top Event</u> - this is the main undesirable event under analysis. <u>Intermediate Event</u> - This describes a condition produced by proceeding events.
	Basic Event	An initiating fault or failure that cannot be developed further. These events are determined from the precision of the analysis.
	AND Gate	Output occur only if all connected inputs exist.
	Inclusive OR Gate	Output will occur if one or more of the connected inputs exist.

Fault tree analysis can have several advantages in process-based systems, such as the bulk materials supply chain. One advantage of FTA is that it can enable the analyst to assess both the probability of failure from several pathways as well as single point failures within a complex system (Clemons & Simmons, 1998). Similar to ETA, this assessment allows for the identification of potential system weaknesses while allowing the analyst to identify specific changes that could reduce system vulnerability (Clemons & Simmons, 1998; Rausand & Hoyland, 2004).

Fault tree analysis works well in complex systems, such as the bulk materials handling system, to identify vulnerabilities within the system. The structure of a fault tree also gives a good framework for analysts to understand a systems-related cause of failure, but the analysis is dependent on careful construction and good input data. If these are not in place, the analysis will be flawed (Rausand & Hoyland, 2004).

FTA has limitations similar to ETA relating to knowledge of the system. It is crucial to the success of FTA that these limitations are heeded by the analyst for a successful assessment of the system. One disadvantage of FTA is that it focuses on one main top event or failure, which can result in a troublesome assessment if the outcome or causal pathways leading to the event are not known (Clemons & Simmons, 1998; Stamatelatos et al., 2002).

As in ETA, bulk materials handling systems are complex (Golan et al., 2004; Thakur et al., 2009) and require analysts that are experienced and understand the system and its causal pathways as a whole to make valid



probability estimates. Because the fault tree leads from the top event to basic event components, good data such as the failure rate of each component must be accurate for the tree to be useful in calculating accurate risk (Clemons & Simmons, 1998; Rausand & Hoyland, 2004).

Some systems are understood very well and have extensive tracing and track while other systems are less precise (Golan et al., 2004). Populating FTA with data from thoroughly tracked systems would likely be more successful than in the systems that are not precisely tracked (Laux & Hurburgh, 2010; Mosher, Laux, & Hurburgh, 2009). In other words, if bad data or poor analyses are used in FTA, the outcome will be flawed and poor decisions may result. Finally, each event under each logic gate must be independent of one another and each event must be an immediate contributor to the next, as displayed in Figure 2 (Clemons & Simmons, 1998; Rausand & Hoyland, 2004). In a complex system such as bulk materials handling, system dependencies may not always follow a causal pathway, which can be problematic in estimating risk.

Risk Assessment Matrix

The third tool discussed is the risk assessment matrix. The risk assessment matrix (RAM) is a presentation of potential exposures or occurrence and potential severities or consequences that, when considered together, identify the level of risk for a given scenario. The matrix is used to conduct a subjective assessment from the data that an analyst or manager has available (Clemons & Simmons, 1998; U.S. DoD, 2012). The risk assessment matrix is derived from risk curves, which are a plotted curve of probability and severity. Defining distinct cut off points to develop categories of risk make the decision making process more clearly defined with pre-determined areas of risk acceptance. (Clemons & Simmons, 1998; U.S. DoD, 2012). Risk assessment matrices are a simple and straightforward way to define what is acceptable or not for a given scenario. It allows managers or analysts to make relatively quick decision choices based on pre-defined acceptable levels of risk in the RAM. Common matrix categories evaluate the likelihood of occurrence and consequence on areas such human injury, environmental damage, monetary loss, and work time lost as a result of the event (Clemons & Simmons, 1998; ioMosaic Corporation, 2009; U.S. DoD, 2012).

The first piece of a RAM is the probability levels with a subjective definition. Table 2 shows an example from Clemons and Simmons (1998). The second piece of a RAM is the level of severity for different targets. The levels of severity can be adjusted to fit specific applications so that the levels are not too broad or precise. Levels can range from catastrophic to negligible. Table 3 shows an example from Clemons and Simmons (1998). The two categorical levels of probability and severity are combined to form a matrix from which risk levels can be determined, as shown in Figure 3 (Clemons & Simmons, 1998).



Table 2. Example of Severity Levels for Multiple Targets

Category	Severity				
	Personnel Injury	Equipment Loss	Product Loss	Down Time	Environmental Effect
I Catastrophic	Death	Greater than 1 million dollars	Greater than 1 million dollars	More than 4 months	Long-term (more than 5 years) damage cost greater than 1 million dollars to correct
II Critical	Severe injury or illness	250 thousand to 1 million dollars	250 thousand to 1 million dollars	2 weeks to 4 months	Medium-term (1-5 years) damage cost between 250 thousand to 1 million dollars to correct
III Marginal	Minor injury or illness	1 thousand to 250 thousand dollars	1 thousand to 250 thousand dollars	1 day to 2 weeks	Short-term (1 Year) damage cost between 1 thousand to 250 thousand dollars to correct
IV Negligible	No Injury or illness	less than 1 thousand dollars	less than 1 thousand dollars	less than 1 day	Minor (readily repairable) damage cost less than 1 thousand dollars to correct

Table 3. Example of Probability Levels

Probability		
Level	Description	Definition
A	Frequent	Likely to occur repeatedly in a system life cycle
B	Probable	Likely to occur multiple times in a system life cycle
C	Occasional	Likely to occur sometime in a system life cycle
D	Remote	Not likely to occur in a system life cycle, but possible
E	Improbable	probability of occurrence cannot be distinguished from zero
F	Impossible	Physically impossible to occur



		Probability					
		F Impossible	E Improbable	D Remote	C Occasional	B Probable	A Frequent
Severity Of Consequences	I Catastrophic				1		
	II Critical				2		
	III Marginal			3			
	IV Negligible						

1	Must suppress to a lower risk
2	Operation permissible for a short time with management signed waiver
3	Operation Permissible
Life Cycle	n years

Figure 3. Example Risk Assessment Matrix

One advantage of RAMs is that it can be used as a management tool with simple input data from an analyst. When using a RAM, a manager can decide which hazards generate the most risk within a system and make mitigation decisions accordingly (Clemons & Simmons, 1998; ioMosaic Corporation, 2009). Unlike FTA and ETA, RAM requires little experience to use. For this reason, it has the potential to prevent problems within the bulk materials handling system on a day-to-day basis, particularly when used with output data from experienced analysts.

Furthermore, the RAM is not specifically designed as a pre or post incident tool. Rather, it can be implemented during the design phase to reduce the risk in the system. It may even be implemented after a system is running to make decisions about mitigating the effects of current hazards (Clemons & Simmons, 1998; U.S. DoD, 2012). This allows bulk materials handling operations the flexibility to implement this before conducting business or during operation if the system has already been established.

An important limitation of RAMs is that this tool does not identify the actual hazards or probabilities, therefore, it must be used in combination with other risk mapping tools to be successful in analyzing a system (Clemons & Simmons, 1998; ioMosaic Corporation, 2009). Additionally, without the valid data on the probability of occurrence or severity, this tool alone will be completely subjective. Though the RAM alone is not powerful enough in bulk materials handling, in combination with other tools it becomes a flexible tool to efficiently make decisions based on predetermined action levels without any professional experience. This tool is most useful for managers who are overseeing day-to-day operations and may encounter a situation that requires an assessment of risk involved before proceeding.



Potential Impact of Risk Mapping

As the management of bulk materials becomes more challenging, tools such as fault tree analysis, event tree analysis, and risk assessment matrix can perform a valuable role in estimating and measuring risk in these systems. Computer systems allow massive calculations and provide data that was difficult if not impossible to access. The tools can also be used to support decision-making, loss prevention, and worker safety within the process-based industries. Their adaptability and relatively straightforward design warrants their further investigation as a risk management tool and for continuous improvement purposes. Both have a high likelihood of providing value for existing systems as well as future bulk handling systems.

References

- Clemons, P. L. & Simmons, R, J. (1998). *System Safety and Risk Management A Guide for Engineering Educators*. Cincinnati Ohio: U.S. Department of Health and Human Services
- Codex. (2007). Working principles for risk analysis for food safety for application by governments (CAC/GL 62-2007). Retrieved from http://www.codexalimentarius.org/download/standards/10751/CXG_062e.pdf
- Ericson, C. A. (2005). *Hazard Analysis Techniques for System Safety*. New Jersey: John Wiley & Sons, Inc.
- Golan, E., Krissoff, B., Kuchler, F., Calvin, L., Nelson, K. & Price, G. (2004). *Traceability in the U.S. Food Supply: Economic Theory and Industry Studies*. Washington, DC: United States Department of Agriculture.
- The Institution of Engineering and Technology. (2010). Quantified risk assessment techniques – Part 2 – Event tree analysis – ETA. *Health & Safety Briefing No. 26b*, October 2010.
- The Institution of Engineering and Technology. (2012). Quantified risk assessment techniques – Part 3 – Fault tree analysis – FTA. *Health & Safety Briefing No. 26c*, August 2012.
- ioMosaic Corporation. (2009). Designing an effective risk matrix [White Paper]. Retrieved from <http://www.iomosaic.com/docs/whitepapers/risk-ranking.pdf>



- Kingman, D. & Field, W. (2005). Using fault tree analysis to identify contributing factors to engulfment in flowing grain in on-farm grain bins. *Journal of Agriculture Safety and Health*, 11(4), 395-405.
- Laux, C. & Hurburgh, C. (2010). Using quality management systems for food traceability. *Journal of Industrial Technology*, 26 (3), 1-10.
- Lindhe, A., Rosen, L., Norberg, T. & Bergstedt, O. (2009). Fault tree analysis for integrated and probabilistic risk analysis of drinking water systems. *Water Research*, 43 (6), 1641-1653.
- Mosher, G.A., Laux, C. & Hurburgh, C. (2009). Using mock recall data to measure continuous quality improvement. *ATMAE 2009 Conference Proceedings Papers*. 97-102
- Rausand, M. & Hoyland, A. (2004). *System Reliability Theory: Models, Statistical Methods, and Applications, Second Edition*. New Jersey: John Wiley & Sons, Inc.
- Stamatelatos, M., Vesely, M., Dugan, J., Fragola, J., Minarick III, J. & Railsback, J. (2002). *Fault Tree Handbook with Aerospace Applications*. Washington, DC: NASA Office of Safety and Mission Assurance.
- Thakur, M. Wang, L. & Hurburgh, C. (2009). Framework for implementing traceability system in the bulk grain supply chain. *Food Engineering*, 95 (4), 617-626.
- Thakur, M. Wang, L. & Hurburgh, C. (2010). A multi-objective optimization approach to balancing cost and traceability in bulk grain handling. *Food Engineering*, 101 (2), 193-200.
- U.S. Department of Defense. (2012). System safety (MIL-STD-882E). Retrieved from <http://www.system-safety.org/Documents/MIL-STD-882E.pdf>
- Vesely, W., Goldberg, F., Roberts, N. & Haasl, D. (1981). *Fault Tree Handbook*. U.S. Nuclear Regulatory Commission, Washington, DC.